Original Research Article

NUCLEATING TECHNIQUES IN FOREST RESTORATION OF A DEGRADED AREA IN A SEASONALLY DRY TROPICAL FOREST, BRAZIL

Abstract: The nucleator techniques have specific and very particular functions, helping the reoccupation of some animals in the area, besides the natural succession. The objective of this study was to evaluate the use of the nucleator techniques of artificial perches and branch windrowing for the establishment of forest restoration in a seasonally dry tropical forest, Brazil. The research was conducted at Experimental Farm Cachoeira de São Porfírio, municipality of Santa Luzia, Paraíba, Brazil, in the period from August 2017 to July 2018. Two nucleator techniques were used, the artificial perches and branch windrowing. For both, the randomized block design was employed, with five treatments composed of the spacing between the structures that composed the respective techniques (5x5m; 10x10m; 15x15m; 20x20m and control treatment), in four repetitions. For the artificial perches the number of seeds and excreta were evaluated, and for the branched perches the height of the branches and their decomposition over time was evaluated. in addition, the water content and temperature of the soil in the experimental area were also analyzed. The artificial perches provided insertion of seeds distributed in three botanical families and excreta to the degraded area, thus incorporating organic matter and enriching the seed bank of the experimental site. The largest number of excreta was obtained on perches with greater distance between them, proving that the spacing of 15x15m is the most suitable. The volumes of branches were altered throughout the experimental period, with a faster decomposition of the branches in the control treatment compared to the other treatments, and their cover provided lower temperatures compared to soil exposed to full sun. Both techniques have high potential for forest restoration in degraded areas in seasonally dry tropical forests.

Keywords: Landscape ecology. Seed dispersal. Ecological succession. Caatinga.

1. INTRODUCTION

Throughout the history of planet Earth, nature has always shown high levels of resilience in the face of geological events that have shaped what we know today. However, after the industrial revolution, the human population has been unleashing disturbances that may affect their quality of life or even the quality of life of future generations, due to the unsustainable exploitation of nature, drastically unbalancing the balance between replenishment of natural resources and human demands, thus arising a major challenge for today's society: to exploit resources in a sustainable way and preserve nature while maintaining its integrity.

The 'Anthropocene' is marked by the increasing transformation of forest ecosystems into agricultural lands (MALHI, 2017). Year after year, areas of large natural forests have been destroyed due to several factors, among them, the conversion of forest soils to agricultural soils, indiscriminate logging, inappropriate land use practices, and construction for human habitation (SAVARI et al., 2020).

Due to these alternative uses of natural resources, anthropic activities generate disruptions in biogeochemical cycles that are primordial to add or even remove genetically distinct species and populations from habitats in the vast majority of terrestrial ecosystems, putting at risk the sustainability of ecological processes as well as ecosystem goods and services (ARNAN et al., 2018).

Anthropic action becomes even more striking in Seasonally Dry Tropical Forests, as is the case of the Caatinga Biome, which covers a large part of Northeastern Brazil. In this biome, in addition to this pressure for natural resources, plants are subject to severe water deficits and high temperatures, leading to greater stresses on the vegetation when compared to other biomes that have greater rainfall and mild temperatures (SANTOS et al., 2014).

Seasonally Dry Tropical Forests represent approximately 42% of all tropical ecosystems, with more than half of them (54.2%) covering South America (MENDIVELSO et al., 2016). The hydrological seasonality of these environments entails several morphological and phenological adaptations in plant species (DIRZO et al., 2011). Of these adaptations, one of the most important is the presence of deciduous species, that the fall of their leaves happens during the dry season (NEVES et al., 2017). In this context, forest restoration and conservation at the global level are key to restoring ecosystem health and achieving the Aichi Biodiversity Targets and the UN Sustainable Development Goals (CHAZDON, 2019; GRISCOM et al., 2017). When it comes to low- to middle-income countries, restoration of forest environments is critical for sustainable development, preservation of cultural identities, and health of communities (FISHER et al., 2019; ZHANG et al., 2019).

Reis and Tres (2007) suggest that the intent of nucleation techniques is to trigger ecological triggers in the natural regeneration process. According to the authors, through nucleation it is possible to form new populations of individuals, new regeneration niches and bring to the landscape a new connectivity. The nucleating techniques have distinct functions and particularities for the environment in which they are inserted and the association of techniques will collaborate for the restoration of the area in a natural way and more similar to its originality (REIS; TRES; BECHARA, 2006).

In view of this, the present research aimed to evaluate the use of the techniques Nucleators artificial perches and branch enmeshment for the establishment of forest restoration in Seasonally Dry Tropical Forest, Brazil.

2. MATERIAL AND METHODS

2.1 Characterization of the study area

The experimental area is inserted in the Desertification Center of the Seridó, in the Cachoeira de São Porfírio Farm, in the municipality of Santa Luzia, Paraíba, Brazil, situated between the coordinates 06º 48' 35" S and 36º 57' 15" W, at 271 m of altitude.

Rainfall in the study region is concentrated between January and April, with annual precipitation ranging from 350 to 800 mm, with a historical average of 600 mm. The dry period occurs between July and December. The average annual temperature detected in the region is 30.7 ºC, with a maximum average occurring in the month of October (31 ºC) and the minimum average in the month of February (29.3 ºC). The average relative humidity is around 63%, with November being the driest month of the year and April the wettest. The average annual insolation is 2981 hours (COSTA et al., 2009).

The degradation stage of the area is high, showing strong signs of anthropic action, with the almost total removal of the original arboreal vegetation. Thus, part of the soil is eroded, where the presence of plant species is rare, with the exception of the species faveleira (*Cnidoscolus quercifolius* Pohl.), capim panasco (*Aristida setifolia* Kunth) and pinhão (*Jatropha curcas* L.).

2.2 Nucleation techniques

2.2.1 Artificial perches

Perches of the "dry" type were installed 2m high with seed collectors fixed at their base. The perches consisted of wooden stems with tree branches attached at the top, simulating a real tree.

A nylon mesh of 1m² was fixed at the base of the perch, always taking care that the structure had a convex shape, approximately 0.20m deep, from the central part to the ends, in order to collect the material brought to the area.

Monthly, all the material contained in the collectors was collected, placed in paper bags and taken to the Laboratory of Mineral Plant Nutrition/CSTR/UFCG for sorting, identification and weighing. The seeds obtained from the collectors were properly identified through literature. The species composition and total seed density (m^{-2}) were quantified at each collection.

2.2.2 Branch windrowing

The branch windrowing was formed by plant residues obtained from preserved areas adjacent to the experimental area, consisting mainly of dead branches.

branches. These branches were arranged in $1m^3$ cores.

Observations were made about the use of the branches by animals and the time of their decomposition. To evaluate the decomposition of the branches over the experimental period, their heights were measured monthly to obtain the reduction in height and consequent decomposition of the forming material over time.

2.3 Water content, soil temperature and rainfall

To determine the soil water content, soil samples were taken from the experimental area, one sample per treatment, taken with a trowel at a depth of 0-20 cm.

In the laboratory the samples were weighed on an analytical balance to obtain the weight of wet soil mass (g) and then placed in an oven at an average temperature of 105 °C for 24 hours to obtain the weight of dry mass of the samples (g).

The calculation for water content was performed using the following formula:

Where:

Wc - water content (%);

Ws - wet soil mass (g);

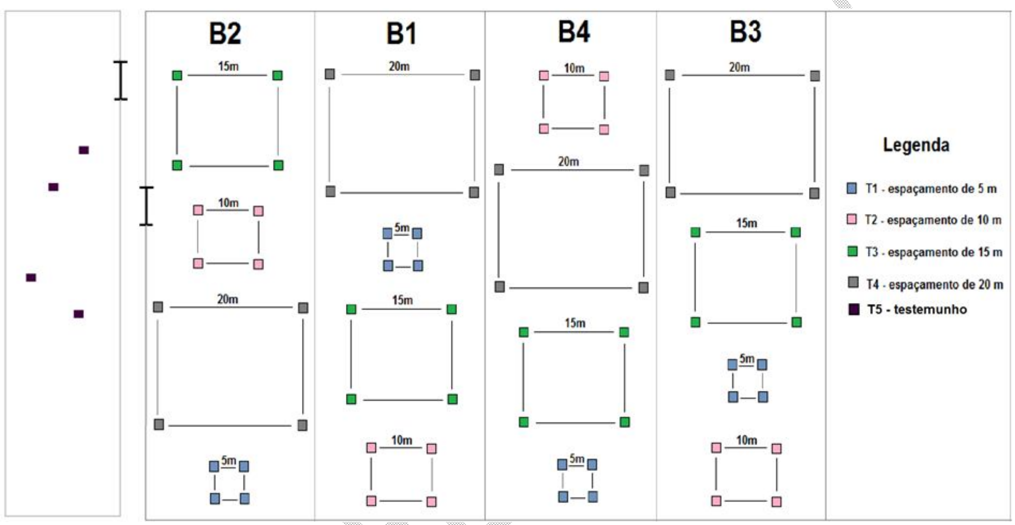
Ds - dry soil mass (g).

The soil temperature was checked monthly inside and outside the branches, at depths of 0.0, 7.5 and 15 cm, with the aid of a portable digital thermometer, between the hours of 7:00 am and 8:00 am. The rainfall data for the area throughout the experimental period were obtained from AESA (Executive Agency for Water Management - PB) (2018).

2.4 Trial design and setup

The statistical design adopted in each experiment was randomized block design, composed of five treatments (spacing between techniques and four repetitions). Each treatment consisted of a module with four experimental units, 5x 5m apart (treatment 1), 10x10m (treatment 2), 15x15m (treatment 3), 20x20mm (treatment 4) and the control treatment, which was inserted into the preserved forest without a pre-defined spacing (treatment 5).

Figure 1 - Sketch of the experimental area, illustrating the arrangement of treatments in each block.



The experiment was installed in August 2017 and collections were performed monthly during the period from August 2017 to July 2018. The experimental period contemplated the rainy and dry periods of the region.

2.5 Statistical analysis

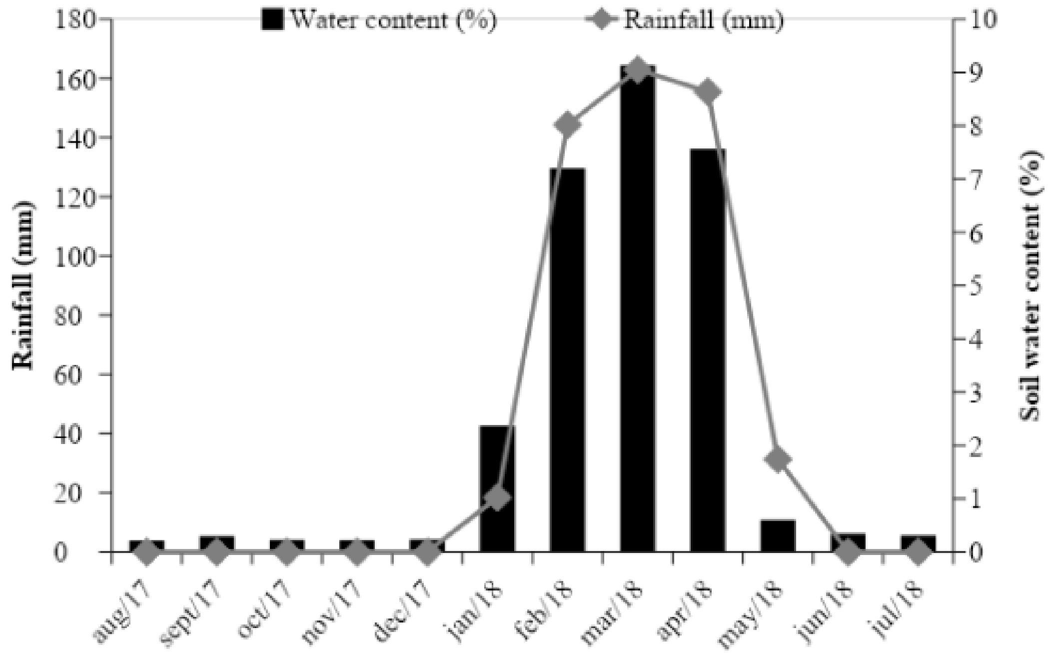
The data were submitted to the analysis of variance and when significant, the means of temperature inside and outside the branches were submitted to the Tukey test and the numbers of seeds and number of excreta were tested by the Scott-Knott test, both at the 5% significance level. The height of branches was subjected to regression analysis according to the significant model and the decomposition between the control and other treatments was analyzed by the Dunnett test at 5% significance level, all tests were performed using the statistical program SAS (SAS, 2011).

3. Results and Discussion

3.1 Rainfall and soil water content

Rainfall during the data collection period totaled 512.4mm. The data of water content in the soil were obtained through monthly collections, presenting their highest percentages in the rainy season (Figure 2).

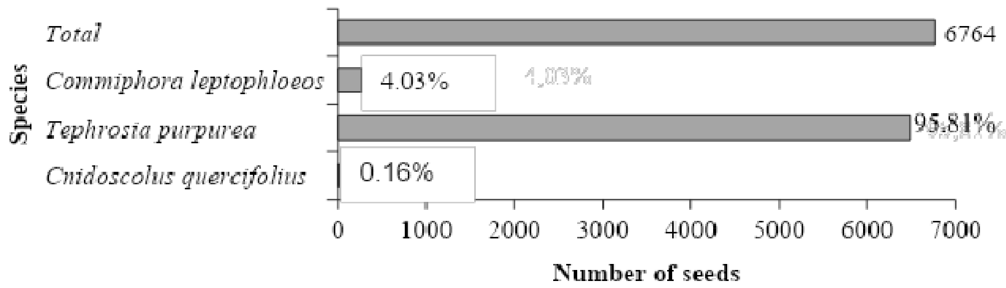
Figure 2 - Total monthly rainfall (mm) and monthly water content (%) occurring at Cachoeira de São Porfírio Farm, municipality of Santa Luzia - Paraíba, Brazil.



3.2 Number of seeds deposited on the artificial perches

Throughout the experimental period, 6764 seeds were collected and identified, distributed in three botanical families, being the species *Commiphora leptophloeos*, belonging to the Burseraceae family, the species *Cnidoscolus quercifolius* belonging to the Euphorbiacea family and the species *Tephrosia purpurea* belonging to the Fabaceae family, where the first two have a tree-like life form and the third has a herbaceous life form (Figure 3).

Figure 3 - Number of seeds collected on artificial perches of different species found in a degraded area in the Seridó Desertification Center, Paraíba, Brasil.



The amount of seeds obtained in this research was higher than the results observed by Guedes (2017) in an experiment conducted with artificial perches in the semi-arid region of Paraíba that quantified 1121 seeds deposited in the collectors in one year of study.

In the process of ecological restoration, herbaceous species are of great importance, as they provide better conditions for the soil to make room for tree species that will compose the forest restoration process. In this sense, the significant amount of seeds of the species *Tephrosia purpurea* and the occurrence of seeds of tree species such as *Commiphora leptophloeos* and *Cnidoscolus quercifolius*, suggest a potential increase to the seed bank and advance to the forest restoration of the area.

During the experimental period, birds were observed visiting the artificial perches, depositing seeds and excrement, which confirms their importance in forest restoration in an area undergoing a desertification process (Figure 4).

Figure 4 - Birds frequenting the artificial perches during the dry and rainy seasons, in a degraded area in the Desertification Center of the Seridó, Paraíba, Brazil.

In Table 1, it is observed differences for the number of seeds over the months studied and also differences between treatments, occurring the highest number of seeds in May 2018, in relation to spacing, it was found that treatments one, two and three are the best to be used. Thus, taking into account the economic feasibility, it is suggested to use the spacing of 15x15 m, due to the smaller number of perches needed per hectare, providing lower expenses per hectare and consequently, lower expenses in the process of forest restoration.

Table 1 - Number of seeds on artificial perches with different spacings, in one year of study,atCachoeiradeSãoPorfírioFarm,Paraíba,Brazil.

Months	Treatments					Media
	5m x 5m	10m x 10m	15m x 15m	20m x 20m	Control	
aug/17	0.0	2.0	0.5	1.0	1.0	0.9B
sept/17	0.0	0.0	0.0	0.0	0.25	0.05B
oct/17	0.0	0.0	0.0	0.0	0.0	0.0B
nov/17	0.0	0.0	0.0	0.0	0.0	0.0B
dec/17	0.0	0.0	0.0	0.0	0.0	0.0B
jan/18	0.0	0.0	0.0	0.0	0.0	0.0B
feb/18	0.0	0.0	0.0	0.0	0.0	0.0B
mar/18	16.75	1.0	7.5	3.5	0.0	5.75B
apr/18	71.75	52.25	67.5	29.25	0.0	44.15B
may/18	494.75	328.5	278.25	198.25	3.75	260.7A
jun/18	55.25	27.0	27.5	22.0	0.75	26.5B
jul/18	0.0	0.25	0.25	0.25	0.0	0.15B
Media	53.21a	34.25a	31.79a	21.19b	0.48b	28.18

*Means followed by the same capital letters in the columns (months) and lower case letters in the rows (treatments) do not differ statistically by the Scott-Knott test at 5% probability level.

The greatest deposition of seeds throughout the experiment occurred during the rainy season, indicating that the results obtained may be associated with the phenology of the species found there, because plants have several mechanisms to disperse their seeds in order to obtain greater propagation. Such results may also be associated with the preference of birds to land on perches with closer spacing as a form of protection.

The diversity and quantity of seeds are subject to seasonal fruiting of plant species belonging to the preserved Caatinga fragment, which is adjacent to the degraded area (GUEDES, 2017). Furthermore, frugivory is not only limited to the direct sustenance provided to the animals that practice it, but it is also a vitally important process for plant populations, in which one of the forms of their natural regeneration is sustained by zoochoric dispersal (JORDANO, 2000).

3.3 Number of nitrogenous excreta deposited on artificial perches

The average number of excreta from birds that visited the artificial perches in the experimental area over the 12-month study period is shown in Table 2. A total of 3238 excreta were found in the collectors over the experimental period.

Table 2 - Number of droppings on artificial perches with different spacings, in one year of study,atCachoeiradeSãoPorfírioFarm,Paraíba,Brazil.

Months	Treatments					Media
	5mx5m	10mx10m	15mx15m	20mx20m	Control	
aug/17	1.0	2.0	2.25	3.0	0.25	1.7D
sept/17	0.5	1.25	1.25	2.0	0.25	1.05D
oct/17	0.5	0.75	0.5	2.5	0.25	0.9D
nov/17	1.0	2.0	1.75	1.75	0.25	1.35D
dec/17	2.25	3.0	1.75	4.75	0.0	2.35D
jan/18	8.25	4.5	6.0	15.75	0.25	6.95D
feb/18	6.25	8.75	8.5	13.75	0.0	7.45D
mar/18	10.0	9.5	15.0	14.5	0.0	9.8D
apr/18	20.25	29.0	27.5	24.25	1.25	20.45C
may/18	44.0	52.5	92.25	89.25	6.25	56.85A
jun/18	15.5	25.75	32.5	36.5	1.75	22.4C
jul/18	26.75	38.25	35.75	52.5	0.0	30.65B
Media	11.35b	14.77b	18.75a	21.71a	0.88c	13.49

*Means followed by the same capital letters in the columns (months) and lower case letters in the rows (treatments) do not differ statistically by the Scott-Knott test at 5% probability level.

There were significant differences regarding the amount of excreta among the months, and the highest mean number of excreta was found in May 2018. In addition, the highest numbers of excreta were found in treatments three and four, evidencing the preference of the birds that frequented the area for more distant perches, possibly due to their preference to move between them. It is once again evident that perches with distances of 15x15m are the most suitable for these areas.

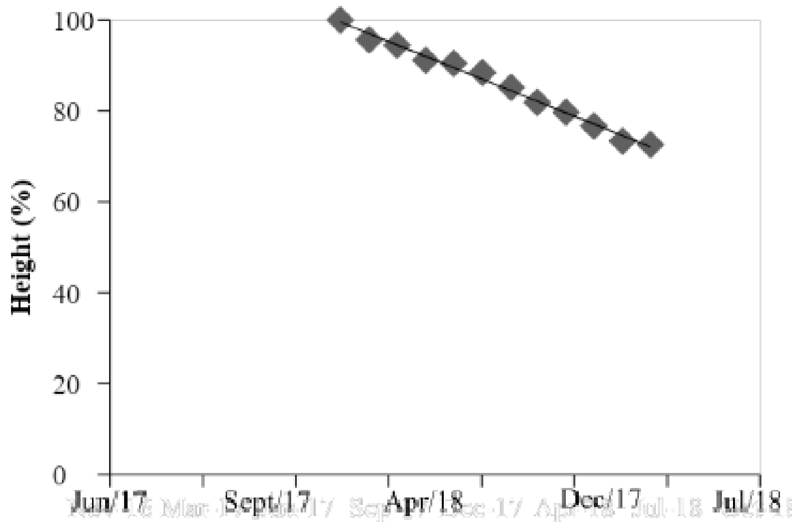
Guedes (2017), conducting a study in a degraded area in the semi-arid region of Paraíba, found that the spacing 20x20m was the most representative, showing 10.61 excreta month^{-1}, highlighting a greater preference for visitation of this spacing by birds and the lowest values were found in the control treatment, as in this study. Once again confirming the preference for more widely spaced artificial perches.

The arrival of these excreta in degraded areas is of fundamental importance, since along with the bird excreta their urine is eliminated, thus giving the excreta a higher concentration of nitrogen compared to cattle and pig manure (PEREIRA; NETO; NÓBREGA, 2013). Such characteristics give the excreta a good capacity to incorporate nutrients back into the soil of degraded areas.

3.4 Branch gathering - shelter and decomposition

The volume occupied by the branches suffered alterations as a function of the time of installation. After a year of experimentation, it was possible to observe that the mean reductions in branches showed significant differences for the months of the study, but no differences between treatments. Considering the height of the branches over the experimental period, the regression model presented below shows how the heights of branches behaved over the period studied (Figure 5).

Figure 5 - Height of branches over the experimental period at Cachoeira de São Porfírio Farm, Paraíba, Brazil.



In addition to serving as shelter for various organisms that are reoccupying the degraded area, the branches also undergo decomposition of its constituent material, providing nutrients to the soil.

The quality of the fit of the regression model is reflected from the coefficient of determination, thus the value found ($R^2 = 0.99$), indicating that the model fits the data adequately and that over the months the height of the branches reduces as a function of their decomposition. Throughout the experiment the branches had an average reduction of 27.4% of its total height, declining from 100% to 72.3% at the end of the experiment.

Leite (2016) conducting an experiment in an area undergoing desertification in the Brazilian semiarid region, also observed a reduction in the height of branched stands, with an average reduction in the volume of branched stands of approximately 16%. The speed of decomposition may be associated with the different environmental and climatic conditions provided by the site over the course of the study, in addition to the composition and size of the branches used.

Silveira et al. (2015) also conducting studies in degraded areas in the Brazilian semi-arid region, found that the material that constituted the litter beds provided a more accelerated decomposition, because the branches that consisted of 100% of height, after twelve months of study, had their height reduced by approximately 40%, however.

Although there were no significant differences between the heights in the treatments used, by means of Dunnett's test at the 5% significance level ($p<0.05$), it was possible to observe that the control treatment obtained the highest rates of branch reduction (16.19%) in relation to the other treatments (table 3).

Table 3 - Comparison between values of the various spacings with control treatment for branch heights at the end of the experiment at Cachoeira de São Porfírio Farm, Paraíba, Brazil.

Spacing	Treatment (%)	Control (%)	Difference
5,0m x 5,0m	85.31	83.81	1.5*
10m x 10m	86.18	83.81	2.36*
15m x 15m	86.70	83.81	2.89*
20m x 20m	87.10	83.81	3.29*
CV%	2.56		
MSD	1.11		

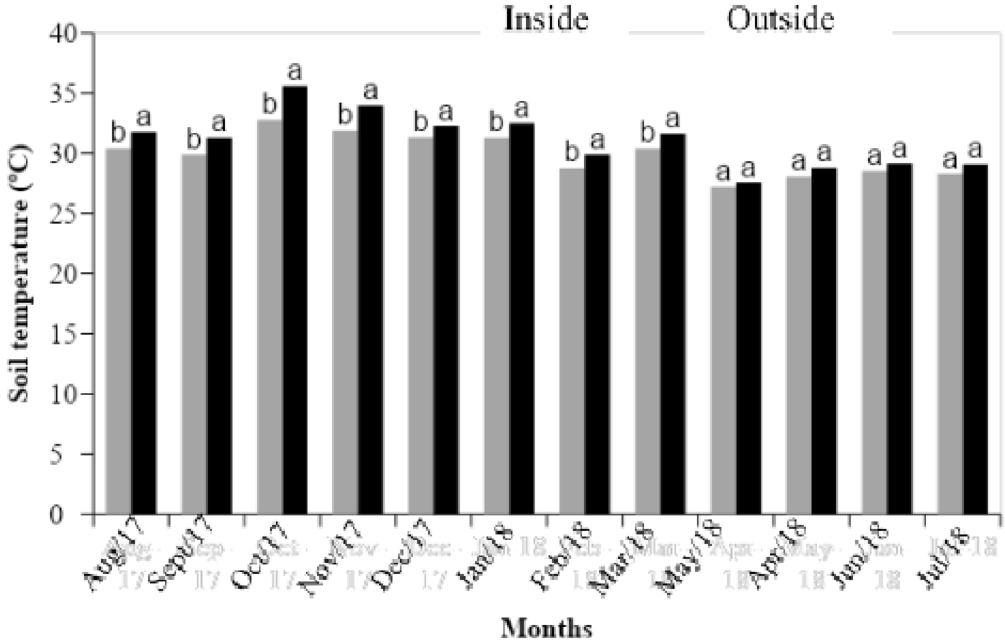
The higher decomposition rates of the control treatment in relation to the other treatments may be associated, probably, by the higher rate of decomposer organisms present in the preserved area in relation to the degraded area where the other treatments were inserted.

Leite (2016) in a study conducted in a seasonally dry tropical forest in Brazil, also found that the control treatment obtained the highest decomposition rates in the experimental period, reaching an average height reduction of 10.78 cm. In addition, he emphasizes that such higher decomposition may be associated with the conditions in which the branch-forming material was found, i.e., in a preserved environment.

3.6 Influence of branch windrowing on soil temperature

By subjecting the soil temperature data to Tukey's test at the 5% significance level ($p<0.05$), it was possible to observe that there was a significant difference between the temperatures inside and outside the branches in most of the months of the study, indicating that branch windrowing provides a significant reduction in soil temperature (figure 6).

Figure 6 - Soil temperature (ºC) inside and outside the branches during the experimental period in the Desertification Center of the Seridó, Paraíba, Brazil.

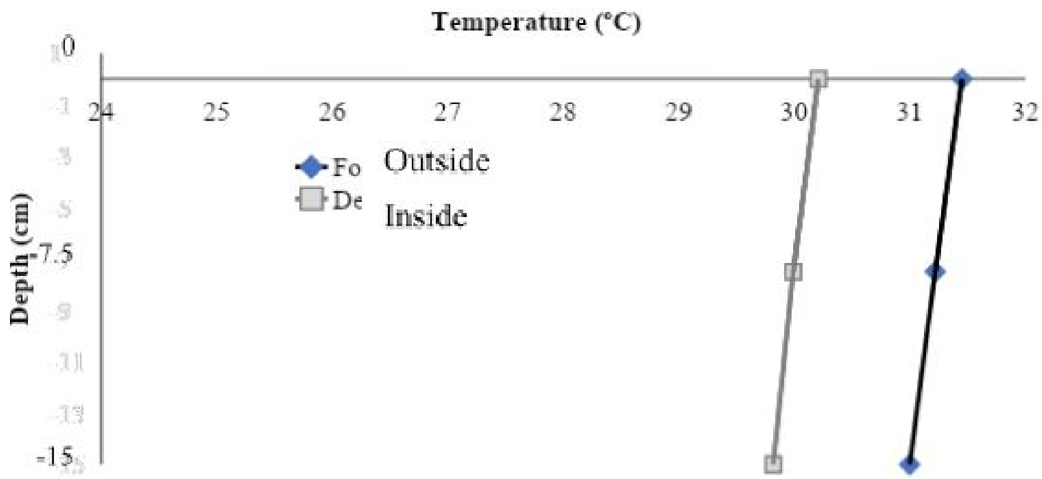


The reduction in soil temperature provided by this technique is essential, considering that in degraded areas the soil is more exposed to solar radiation, reaching high temperatures, drastically affecting the edaphic fauna, as well as the organisms on its surface. In addition, the shelter provides more suitable environments for organisms to take shelter with lower temperature ranges, favoring the recolonization of the area and, in an associated way, forest restoration.

Leite (2016) analyzing soil temperatures in degraded areas in the state of Paraíba (Brazil), also found that for most of the period studied the soil temperatures were lower in the part that was covered by the branches and attests that such data indicate their efficiency in maintaining a lower soil temperature, thus providing shelter for animals of the local fauna that disperse seeds there. According to Belan et al. (2013) plant residues deposited on the soil protect it from water loss and excessive heating.

Furthermore, throughout the experimental period it was possible to verify and observe that the soil temperature was lower as the depth increased (Figure 7).

Figure 7 - Annual soil temperature (ºC) at different depths, observed (0.0; 7.5; 15 cm) inside and outside the branches, during twelve months of studies carried out at Cachoeira de São Porfírio Farm, Paraíba, Brazil.



It was also possible to observe that the average annual soil temperature was lower inside the branches in the three depths analyzed, demonstrating that the use of the technique provides shelter with a more pleasant temperature for the fauna, making it favorable for a greater visitation of dispersers and decomposers in the degraded area and a greater protection for the seed bank, helping to maintain its viability. The use of the litter beds by the dispersers is shown in figure 8.

Figure 8 - Seed-dispersing bird eggs deposited in branch galleries at Fazenda Cachoeira de São Porfírio, Paraíba, Brazil.

The results obtained in this research support studies conducted by Gomes (2015), who, evaluating soil temperatures at the same depths as in this study, concluded that there was a decrease in soil temperature as soil depth increased, proving the relationship between increasing depth and reducing the range of variation of soil temperature. Furthermore, Gasparim et al. (2005) attest that one of the most important factors in the process of seed germination and plant development is soil temperature.

4 CONCLUSIONS

- The artificial perches provided insertion of seeds and excreta to the degraded area, incorporating organic matter and enriching the seed bank;
- Artificial perches with a distance of 15x15m are the most suitable for use in environments with these characteristics;
- The branches provide nutrients to the soil through their decomposition, reduce soil temperature and provide shelter for fauna;
- The data obtained in this study provide information that will assist studies and forest restoration programs in seasonally dry tropical forests, especially with regard to fauna-flora interaction.

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